TITLE OF THE INVENTION

Projection Optical System and Exposure Apparatus with the same

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to a projection optical system which projects an image of a first plane onto a second plane, and particularly, a projection optical system which is suitable for reduction-projection-exposing a semiconductor pattern which is formed on a reticle (mask) at a first plane onto a substrate (wafer) at a second plane, and an exposure apparatus provided with the projection optical system.

Background of the Related Art

When a semiconductor element is fabricated, a projection exposure apparatus is used which transfers an image of a pattern on a reticle onto a wafer coated by a resist via a projection optical system. As miniaturization of patterns of semiconductor integrated circuits to be transferred has progressed, high resolution is demanded for a projection optical system which is used for wafer exposure. In order to meet the demand, it is necessary to proceed with procedures such as shortening the wavelength of an exposure light or increasing the numerical aperture of a projection lens optical system.

Recently, in order to respond to miniaturization of transfer patterns, KrF excimer laser (wavelength 248 nm) has begun to be used instead of an i line (wavelength 365 nm) as an exposure light source. Furthermore, ArF excimer laser (wavelength 193 nm) has also begun to be used.

Recently, particularly with respect to ArF excimer laser, narrowing of the band region of a laser light source has progressed by using optical elements. However, a half width of approximately several pm still remains. If this type of light source is used as a light source of a projection optical system in which most of the structural glass material is silica, chromatic aberration, which cannot be ignored, is generated. As a result, image contrast deteriorates, causing image deterioration.

Therefore, narrowing of the band region of a laser is desired, but narrowing the band region of a laser is not easy, and has limitations because there are many problems such as deterioration of a narrow band region element over time. Therefore, by adding other glass types to the structural lens, the chromatic aberration can be corrected. Fluorite is used for the other glass type. Fluorite can also control irradiation fluctuation in addition to chromatic aberration. If a laser in which narrowing of the band region cannot very much

further proceed is used as a light source, and an optical system is structured by using fluorite, the majority of the structural members of the optical system also have to be fluorite. However, in addition to the high cost of fluorite, it is known that a performance capability of an optical system with fluorite deteriorates because processability is poor, and surface changes due to temperature fluctuation are significant.

SUMMARY OF THE INVENTION

Thus, an object of this invention is to correct chromatic aberration and control irradiation fluctuation while design performance capability is maintained even when a laser light source is used which has not been well developed with respect to a narrow band region.

In order to accomplish the above-mentioned object, a projection optical system according to one aspect of this invention is a projection optical system which projects an image of a first plane onto a second plane. The projection optical system, includes:

a lens component formed of fluorite;

a lens component formed of silica;

a first lens group including at least one lens component formed of fluorite and having a positive refractive power;

a second lens group arranged in an optical path between the first lens group and the second surface and having a negative refractive power; and

a third lens group arranged in an optical path between the second lens group and the second surface and having a positive refractive power;

wherein when the number of the lens components formed of silica is Snum, the number of the lens components formed of fluorite is Cnum, and a numerical aperture of the second surface side of the projection optical system is NA, the following conditions are satisfied:

Snum>Cnum (1)

NA>0.75 (2).

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is an optical path diagram of a projection optical system of a first embodiment of this invention.

Fig. 2 shows aberration diagrams of a projection optical system of the first embodiment of this invention.

Fig. 3 is an optical path diagram of a projection optical system of a second embodiment of this invention.

Fig. 4 shows aberration diagrams of a projection optical system of the second embodiment of this invention.

Fig. 5 is a structural diagram of a projection exposure apparatus related to embodiments of this invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

In a projection optical system according to the above-mentioned aspect of the invention, a first lens group having a positive refractive power relays a telecentric light beam emitted from a first surface to a second lens group. At the same time, positive distortion is generated in advance, and by so doing, negative distortion generated in the second and third lens groups is corrected. Furthermore, the second lens group, having a negative refractive power, mainly contributes to the correction of Petzval's sum and accomplishes flatness of the image plane. The third lens group, having a positive refractive power, telecentrically projects an image of a light beam relayed from the second lens group onto the second plane, and mainly plays a role of imaging in a state in which generation of spherical aberration is controlled as much as possible.

With respect to silica glass material for ArF laser, it is known that irradiation fluctuation such as absorption, compaction, or the like is generated. Here, by using at least one lens of a fluorite glass material for the first lens group having a positive refractive

power, aberration deterioration of irradiation fluctuation due to silica glass material can be controlled. In the first lens group, a light beam (partial aperture) going through a center of an optical axis is relatively distant on a lens surface from a light beam going through a peripheral area, so when irradiation fluctuation is generated in the first lens group, the difference between the peripheral area and the center of a projection area or the like becomes significant, and aberration fluctuation becomes large. Thus, by using fluorite for the first lens group, aberration deterioration due to irradiation fluctuation can be effectively controlled.

Condition (1) establishes the necessary number of fluorite elements for a structure of a projection optical system according to the above-mentioned aspect of the invention. By using the structure of the projection optical system of this invention, the number of lenses can be reduced, the entire optical system can be made smaller, and axial chromatic aberration can be made proportionally small. Therefore, chromatic aberration can be reduced, so the number of fluorite members can be reduced, and in the projection optical system according to the above-mentioned condition, a design performance capability can be maintained in the same manner as in a conventional projection optical

system.

Condition (2) establishes a numerical aperture which can be accomplished by the structure of the projection optical system according to the above-mentioned aspect of the invention. As the entire optical system is made smaller, a refractive power of a third lens group having a positive refractive power becomes strong, and the projection optical system with the high numerical aperture of condition (2) can be accomplished. At that time, in order to further miniaturize the optical system while maintaining various aberrations, it is preferable that at least one aspherical surface is provided within the second lens group having a negative refractive power. Furthermore, when the minimum of condition (2) is exceeded, power of the third lens group is weakened, the entire projection optical system becomes larger, and chromatic aberration becomes poor in proportion.

In the projection optical system according to the above-mentioned condition, it is preferable that at least one lens component among lens components formed of the fluorite within the first lens group has a positive refractive power. As described above, with respect to the structure of the first lens group, effects of aberration deterioration due to irradiation fluctuations in the first lens group, such as coma, the

difference between the periphery and the center in the projection area, or the like are larger than such effects in other lens groups. In particular, in a convex lens, with respect to an optical path length going through a glass material, a light beam going though at the optical axis center is longer than a light beam going through the periphery; therefore, effects of irradiation fluctuation on a glass material are easily generated. Thus, from the standpoint of efficiently controlling aberration fluctuation due to irradiation fluctuation, it is preferable that a fluorite glass material is used for lenses having a positive refractive power. Additionally, from a perspective of chromatic aberration correcting occurring due to the difference in the refractive index of fluorite, it is preferable that a fluorite glass material is used for lenses having a positive refractive power.

Furthermore, in the projection optical system according to the above-mentioned aspect, it is preferable that the third lens group has at least one lens component formed of fluorite. A light beam which is diverged by the second lens group is converged by the third lens group, so each lens of the third lens group has a high irradiating energy density. This causes compaction, which is a type of irradiation

fluctuation. If a fluorite glass material is used for the third lens group, an effect can be obtained which reduces the effect of this compaction. Furthermore, if a fluorite glass material is used for a glass material with thickness close to the plane at which the irradiating energy density is focused, compaction can be further effectively corrected.

In the projection optical system according to the above-mentioned condition, when the distance between the first surface and the second surface is L, the distance between the first surface and the lens surface of the first lens group closest to the second surface side is L1, and the focal length of the second lens group is f2, it is preferable that the following conditions are satisfied:

$$0.2 < L1/L < 0.5 \qquad (3)$$

$$0.03 < -f2/L < 0.10 \qquad (4)$$

Condition (3) establishes an appropriate positive refractive power of the first lens group for the entire system. If the maximum value of condition (3) is exceeded, negative distortion generated in the second lens group cannot be corrected. If the minimum value of condition (3) is exceeded, it is not good because positive distortion of a higher order is generated.

Condition (4) establishes an appropriate negative refractive power of the second lens group for the

entire system. If the maximum value of condition (4) is exceeded, correction of Petzval's sum becomes insufficient, and deterioration of flatness of an image plane occurs. If the minimum value of condition (4) is exceeded, spherical aberration of a high order is generated, and image contrast deteriorates.

In the projection optical system in the above-mentioned aspect, it is preferable that the first lens group has at least one aspherical lens surface. Because of this, distortion can be corrected even further.

In the projection optical system in the above-mentioned aspect, the lens group which constitutes the projection optical system can also be constituted by the first, second, and third lens groups only.

In the projection optical system in the above-mentioned aspect, the projection optical system can also be structured so as to be optimized with respect to light having a center wavelength of 200 nm or less.

The following explains details of embodiments of this invention based on the drawings. Additionally, with respect to structural elements having the same function and structure, repetitive explanation is omitted in the following explanation and the drawings use the same symbols.

(First Embodiment)

Fig. 1 is a diagram showing a lens structure of a

projection optical system according to a first embodiment of this invention. The projection optical system of this embodiment uses silica SiO_2 and fluorite CaF_2 as a glass material and telecentrically projects an image of a reticle R at a first surface onto a wafer W at a second surface. This projection optical system is constituted by, in order from the reticle R side, a first lens group G1 having a positive refractive power, a second lens group G2 having a negative refractive power, and a third lens group G3 having a positive refractive power. The first lens group G1 includes a lens LP11 having a positive refractive power formed of fluorite in addition to ASP11 and ASP12 which are aspherical-shaped lens surfaces. The third lens group G3 includes lenses LP12, LP13, LP14, and LP15 formed of fluorite. An aperture stop AS is arranged within the third lens group G3, and a reference wavelength of this projection optical system is 193.3 nm.

Various values of the projection optical system according to the first embodiment are shown in Table 1. Furthermore, aspherical coefficients of the respective aspherical surfaces are shown in Table 2. With respect to an aspherical surface, when height in a direction perpendicular to the optical axis is y, distance (sag amount) along the optical axis from a tangent plane at a vertex of the aspherical surface to a position on the

aspherical surface at height y is Z, a radius of curvature at the vertex is r, a conical coefficient is K, and aspherical coefficients of an n order are A-F, the following equation can be expressed:

$$Z = (y^2 / r) / [1 + \{1 - (1 + K) \cdot y^2 / r^2\}^{1/2}] + A*y^4+B*y^6+C*y^8+D*y^{10}+E*y^{12}+F*y^{14}$$

Here, mm can be used as one example of the units for the radius of curvature and surface interval in various values of this embodiment. The following shows an index of refraction of each glass material at the wavelength of 193.3 nm.

SiO_2 1.5603261

CaF_2 1.5014548

[Table 1]

Surface Number	Radius of Curvature	Surface Interval	Glass Material
		56.57	
1	388.465	23.27	SiO2
2	177.000	42.53	
3	-120.028	15.00	SiO2
4	-752.332	16.54	
5	-193.722	44.12	SiO2
6	-192.988	1.00	
7	-799.710	42.35	SiO2
8	-240.979	1.00	
9	666.130	51.12	SiO2
10	-543.380	1.00	
11	299.996	49.64	SiO2
12	INFINITY	1.00	
13	276.988	35.60	SiO2
14	991.456	1.00	
15	252.935	30.34	CaF2
16	574.560	30.59	
17	687.760	19.37	SiO2
18	143.863	30.27	
19	-399.976	15.00	SiO2
20	170.000	87.67	
21	-128.314	26.18	SiO2
22	804.730	21.59	
23	-570.040	51.47	SiO2
24	950.000	10.24	
25	INFINITY	35.89	CaF2
26	-250.424	1.02	
27	INFINITY	41.69	CaF2
28	-262.449	13.09	
29	290.060	56.21	SiO2
30	1757.000	26.96	
31	INFINITY	15.03	SiO2
32	276.988	34.69	
33	533.910	48.23	SiO2
34	-471.548	15.61	
35	INFINITY	32.96	SiO2
36	-490.708	2.60	
37	199.138	42.55	SiO2
38	439.306	3.65	
39	170.020	49.30	SiO2
40	300.000	1.66	
41	154.428	45.93	CaF2

42	522.270	5.77	
43	INFINITY	60.00	CaF2
44	1687.460	11.35	

[Table 2]

Aspherical Coefficients

Surface 2

K : 0.000000

A :-.106010E-06 B :0.204228E-11 C :-.588237E-16

D :0.112269E-20

Surface 14

K : 0.000000

A :0.417491E-08 B :0.514111E-13 C :-.666592E-18

D :0.141913E-22

Surface 20

K : 0.000000

A :0.166854E-07 B :0.370389E-12 C :-.138273E-16

D :-.304113E-20

24 surfaces

K : 0.000000

A :0.361963E-07 B :-.679214E-12 C :-.128267E-16

D :0.908964E-21 E :-.121007E-25

Surface 40

K : 0.000000

A :-.179608E-07 B :0.149941E-12 C :-.128914E-17

D :-.506694E-21 E :0.204017E-25 F :-.730011E-30

The following shows the condition corresponding values.

Snum = 17, Cnum = 5

NA = 0.78

$L = 1248.653$

$L1 = 412.086$

$f2 = -45.108$

$L1 / L = 0.330$

$-f2 / L = 0.036$

Fig. 2 shows horizontal aberration (coma) in a tangential direction and in a sagittal direction of a projection optical system of this embodiment. In the diagram, Y represents the image height, and the maximum image height in the projection optical system of this embodiment is 13.7. In the diagram, solid lines show aberration at a wavelength of 193.3060 nm, dotted lines show aberration at the wavelength of 193.3064 nm, and single-dot chain lines show aberration at the wavelength of 193.3056 nm, respectively. As is clear from the aberration diagrams, with respect to the projection optical system of this embodiment, chromatic aberration can be corrected well within the range of the image height 0 to the maximum image height 13.7.

(Second Embodiment)

Fig. 3 is a diagram showing a lens structure of a projection optical system according to a second embodiment of this invention. The projection optical system of this embodiment uses silica SiO_2 and fluorite CaF_2 as a glass material and telecentrically projects an image of a reticle R at a first surface onto a wafer W at a second surface. This projection optical system is constituted by, in order from the reticle R side, a first lens group G1 having a positive refractive power, a second lens group G2 having a negative refractive power, and a third lens group G3 having a positive

refractive power. The first lens group G1 includes lenses LP21, LP22, LP23, LP24, LP25, and LP26 having a positive refractive power formed of fluorite in addition to ASP21 and ASP22 which are aspherical lens surfaces. The third lens group G3 includes lenses LP27, LP28, LP29, LP30, and LP31 formed of fluorite. An aperture stop AS is arranged within the third lens group G3. The reference wavelength of this projection optical system is 193.3nm.

Various values of the projection optical system according to the second embodiment are shown in Table 3. Furthermore, aspherical coefficients of the respective aspherical surfaces are shown in Table 4. The definition of the aspherical coefficients is the same as in the above-mentioned equation. Here, mm can be used as one example for the units of the radius of curvature and surface interval in various values of this embodiment.

[Table 3]

Surface Number	Radius of Curvature	Surface Interval	Glass Material
		68.91	
1	∞	12.52	SiO2
2	396.770	3.00	
3	254.008	24.42	CaF2
4	-934.473	3.00	
5	-12906.162	12.00	SiO2
6	155.270	48.71	
7	-138.969	19.68	SiO2
8	-365.690	12.17	
9	-721.284	42.56	CaF2

Surface Number	Radius of Curvature	Surface Interval	Glass Material
10	-372.350	14.41	
11	8373.957	52.39	CaF2
12	-354.413	8.35	
13	1031.713	49.83	SiO2
14	-549.575	21.26	
15	249.361	64.78	CaF2
16	1823.143	3.00	
17	291.668	38.62	CaF2
18	811.496	3.72	
19	211.542	26.55	CaF2
20	282.982	3.52	
21	150.387	23.88	SiO2
22	168.182	36.14	
23	-3641.124	12.00	SiO2
24	125.009	38.28	
25	-156.902	14.19	SiO2
26	123.218	43.61	
27	-116.259	12.95	SiO2
28	1233.016	10.60	
29	-813.248	37.67	CaF2
30	-193.265	3.00	
31	-368.334	26.36	SiO2
32	-224.645	3.01	
33	1410.985	63.02	SiO2
34	-218.896	4.24	
35	INFINITY	4.18	
36	326.130	46.86	CaF2
37	-1078.234	17.43	
38	-378.423	57.18	SiO2
39	1092.919	84.29	
40	265.072	64.79	CaF2
41	-1076.165	3.15	
42	175.673	39.40	SiO2
43	389.870	3.07	
44	132.696	44.00	SiO2
45	558.221	12.33	
46	-1378.349	12.26	SiO2
47	409.951	6.01	
48	96.901	24.21	CaF2
49	164.260	11.54	
50	333.758	18.07	CaF2
51	2155.618	12.21	

[Table 4]

Aspherical coefficients

Surface 2

K : 0.000000

A :0.377826E-07 B :0.1834493E-11 C :-.861369E-16

D :-.310456E-20

Surface 6

K : 0.000000

A :-.119582E-06 B :0.572777E-12 C :0.258461E-16

D :-.174207E-20

Surface 26

K : 0.000000

A :0.101023E-06 B :-.116323E-10 C :-.588509E-15

D :0.298472E-19

Surface 47

K : 0.000000

A :0.435107E-07 B :-.237192E-11 C :-.246845E-15

D :0.156567E-19

The following shows the condition corresponding values.

Snum = 14, Cnum = 11

NA = 0.8

L = 1323.330

L1 = 557.251

f2 = -40.547

L1/L = 0.421

-f2/L = 0.031

Fig. 4 shows horizontal aberration (coma) in a tangential direction and in a sagittal direction of a projection optical system of this embodiment. In the diagram, Y represents the image height, and the maximum image height in the projection optical system of this embodiment is 13.7. In the diagram, solid lines show aberration at a wavelength of 193.3060 nm, broken lines show aberration at the wavelength of 193.3064 nm, and single-dot chain lines show aberration at the wavelength of 193.3056 nm, respectively. As is clear from the aberration diagrams, chromatic aberration of the projection optical system of this embodiment is corrected well within the range of the image height 0 to the maximum image height 13.7.

Fig. 5 is a structural diagram of a projection exposure apparatus to which the projection optical system of the first or second embodiments is applied as a projection optical system PL. A projection negative plate in which a predetermined pattern is formed is arranged on the reticle R surface of the projection optical system PL. A wafer W coated by a photoresist is arranged, as a workpiece, at the wafer W surface of the projection optical system PL. The reticle R is held on a reticle stage RS, and the wafer W is held on a wafer stage WS. Above the reticle R, an illumination optical system IS is arranged which includes the exposure light

source and uniformly illuminates the reticle R. Here, ArF laser is used as the exposure light source.

Exposure light supplied from the light source substantially uniformly illuminates the reticle R via an (undepicted) optical system within the illumination optical system IS. In the optical system within the illumination optical system IS may also be included, for example, a fly's eye lens and/or an internal surface reflective type integrator which uniformizes the irradiation distribution of exposure light, an optical integrator which forms a planar light source of a predetermined size and shape, a variable field stop (reticle blind) which regulates the size and shape of the illumination region on the reticle R, and/or an optical system such as a field stop imaging optical system which projects an image of the field stop onto the reticle. An image of the pattern of the reticle R which has been illuminated is reduced by the projection magnification via the projection optical system PL, exposed and transferred onto the wafer W.

Preferred embodiments of this invention were explained with reference to the attached drawings. However, this invention is not limited to the above-mentioned examples. It is clear that one of ordinary skill of the art can reach various modifications and changes within the technical field as set forth in the

scope of the claims. It is also understood that such modifications are also part of the scope of the claims of this invention.

For example, an example using ArF laser as a light source was explained in the above-mentioned example, but this invention is not limited to this.

Thus, in the projection optical system of the above-mentioned embodiments as explained in detail, even when a laser light source whose band region has not been narrowed very much is used, or when a fluorite glass material is not used to the maximum extent, correction of chromatic aberration and control of irradiation changes can be suitably performed while design performance capability is maintained. Furthermore, in the projection exposure apparatus of the above-mentioned embodiments, a fine circuit pattern can be formed at high resolution by using an exposure light source having a short wavelength.